Bevilacqua Research Corporation

A Dialectic Approach To Moving Target Indicator (MTI) Correlation

Final Technical Report

Contract Number F19628-98-C-0042

February 26, 2001

BRC – TR – 00400 - 01 - 003

Prepared By:
David J. Skipper

Bevilacqua Research Corporation
P.O. Box 14207
Huntsville, AL 35815
Voice: (256) 882-6229
Fax: (256) 882-6239

Prepared For:
Electronic Systems Command
Hanscom Air Force Base, MA

Form SF298 Citation Data

Report Date *("DD MON YYYY")* 26022001	Report Type N/A	Dates Covered (from... to) *("DD MON YYYY")* 27051999 26022001

Title and Subtitle A Dialectic Approach to Moving Target Indicator (MTI) Final Technical Report	**Contract or Grant Number** F19628-98-C-0042
	Program Element Number
Authors Skipper, David J.	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Bevilacqua Research Corporation 4040 South Memorial Parkway, Suite B2 Huntsville, Alabama 35802	**Performing Organization Number(s)**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Monitoring Agency Acronym**
	Monitoring Agency Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes	
Abstract The problem examined by this research is tracking, with low update rates, on ground vehicles. Tracking solely by statistical prediction is inadequate for infrequently observed targets that exhibit non-deterministic behavior. The approach used here is to assume non-deterministic but rationale behavior will govern the targets. The method used to track is then to estimate the rationale behind the tracking by modeling that rationale using sophisticated knowledge modeling techniques. This report contains the additional results of the second year of research on moving target tracking of non-deterministic targets using low update rates for the observations. The first years effort centered on building the structure needed for tracking. The original intent was that the basic structure was ready to receive the knowledge needed for tracking at the end of the first year and that knowledge would be installed during the second year. A lack of data sets made that impossible, so the second year, in the end, focused on technical improvements in the system.	
Subject Terms Moving Target Indicators; Knowledge based tracking; Conceptual Graphs	
Document Classification unclassified	**Classification of SF298** unclassified

Classification of Abstract unclassified	Limitation of Abstract unlimited
Number of Pages 27	

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
26-02-2001

2. REPORT TYPE
Final Technical Report

3. DATES COVERED *(From - To)*
27-05-1999 to 26-02-2001

4. TITLE AND SUBTITLE
A Dialectic Approach to Moving Target Indicator (MTI) Final Technical Report

Volume : ()

5a. CONTRACT NUMBER
F19628-98-C-0042

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Skipper, David J; Author

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Bevilacqua Research Corporation
4040 South Memorial Parkway,
Suite B2
Huntsville, Alabama 35802

8. PERFORMING ORGANIZATION REPORT NUMBER
BRC-TR-00400-01-003

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
ESC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
A Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The problem examined by this research is tracking, with low update rates, on ground vehicles. Tracking solely by statistical prediction is inadequate for infrequently observed targets that exhibit non-deterministic behavior. The approach used here is to assume non-deterministic but rationale behavior will govern the targets. The method used to track is then to estimate the rationale behind the tracking by modeling that rationale using sophisticated knowledge modeling techniques. This report contains the additional results of the second year of research on moving target tracking of non-deterministic targets using low update rates for the observations. The first year's effort centered on building the structure needed for tracking. The original intent was that the basic structure was ready to receive the knowledge needed for tracking at the end of the first year and that knowledge would be installed during the second year. A lack of data sets made that impossible, so the second year, in the end, focused on technical improvements in the system.

15. SUBJECT TERMS
Moving Target Indicators; Knowledge based tracking; Conceptual Graphs

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Unclassified Unlimited	21	David Skipper / 256-882-6229

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Abstract

The problem examined by this research is tracking, with low update rates, on ground vehicles. Tracking solely by statistical prediction is inadequate for infrequently observed targets that exhibit non-deterministic behavior. The approach used here is to assume non-deterministic but rationale behavior will govern the targets. The method used to track is then to estimate the rationale behind the tracking by modeling that rationale using sophisticated knowledge modeling techniques. This report contains the additional results of the second year of research on moving target tracking of non-deterministic targets using low update rates for the observations. The first year's effort centered on building the structure needed for tracking. The original intent was that the basic structure was ready to receive the knowledge needed for tracking at the end of the first year and that knowledge would be installed during the second year. A lack of data sets made that impossible, so the second year, in the end, focused on technical improvements in the system.

Table of Contents

List of Figures

List of Tables

Part

1

Program Description

Overview

Summary

The research reported here is a Phase II Small Business Innovative Research (SBIR) program. A Phase I effort assessed the feasibility of performing moving target tracking of non-deterministic, low update rate targets. This knowledge based approach offered sufficient promise to call for further investigation. As a result the Phase II contract was awarded to extend the research. The approach was to continue to focus on tracking by using extended knowledge about the rational behavior of each target. This approach assumes that a vehicle, while non-deterministic in a statistical sense, is somewhat constrained, both by physical laws and the situation at hand. This report contains the status and results at the end of the program.

Introduction

The purpose of this report is to document the progress and accomplishments in the final year of the Bevilacqua Research (BRC) advanced tracker development program. This tracker is being developed under the Small Business Innovative Research (SBIR) Contract #F19628-97-C-0047, "A Dialectic Approach To Moving Target Indicator (MTI) Correlation."

Historical Background

Moving Target Indicator (MTI) systems report radar responses only for targets which are in motion. For large areas, the revisit time for an individual target can be quite large. If that target does not have a highly deterministic behavior, then frame to frame track association becomes quite difficult. Methods that use deterministic behavior in a statistical sense can incorrectly associate the tracks. When dealing with high priority time critical targets, this invalid association can cause wasted resources or, even worse, loss of assets due to failure to neutralize the target.

Because of the importance of this problem, Bevilacqua Research Corporation (BRC) performed a Phase I Small Business Innovative Research (SBIR) project. This SBIR investigated the use of novel knowledge modeling techniques to model the vehicle behavior so as to provide a solution to the track association problem. The Phase I effort used a simple data set and a Warlord notebook interface to establish a data stream for a separate tracker. This Phase I study showed that the novel knowledge models employed could track basic cases. The success of the Phase I effort allowed BRC to begin a Phase II SBIR, with the goals to extend the approach and to place the resulting tracker into a government platform for future field-testing. The Phase II SBIR is a two-year program to develop the tracker system. This report represents the final report for this project. Additional details may be found in the First Annual Report. The intent of the first year of the Phase II effort was to develop the infrastructure needed to support a tracker. The emphasis in the second year was to insert the knowledge required to produce a robust tracker. Unfortunately, data support for knowledge acquisition was not available, despite numerous attempts by various government groups, and an extension in time for the program. This and the demise of the Time Critical Targeting Aid (TCTA) support led to a less than conclusive finish to the project.

Summary of the Program

The overall goal of this research is to demonstrate the validity of the knowledgeable approach to tracking for situations in which conventional tracking filters were unsuitable or unworkable. This approach assumes that each target is constrained by the physical world and by trained behaviors as well as rational plans, allof which compel the target to behave in selected manners. The program is designed to build a method of testing these ideas and then to support extensive testing in real situations.

This effort has three objectives to support the previously stated goal:

1) Identify and define the interfaces needed to install the tracker in a government platform. The platform was to be the TCTA. Unfortunately, the government was unable to obtain release of the interface specifications needed for that system.

2) Develop the interfaces, and the associated software, needed to install the tracker in a government platform. Due to lack of interface specifications, BRC was unable to install the system in TCTA as originally desired, and was forced to develop a standalone system, with its own interfaces.

3) Build a smart tracker, which can connect to the defined interfaces within a specified government platform. Intelligence requires knowledge behind the processing. This knowledge was to be acquired from data sets made available to BRC, along with basic ground truth data to support knowledge engineering. These data sets were never provided to BRC.

Participants

BRC is the sole contractor in this research effort. The BRC point of contact is Dr. David Skipper, (256) 882-6229 extension 105. The government technical contact is Ms Gerri Malone, (781) 271-3187.

Document Description

The remainder of this document consists of two parts. The first part is the technical description and the second part is the results of the project. Because the effort in the first year was to develop a platform to support the knowledge modeling and testing, the technical description for the first year consisted of the top-level system design. This report focuses on the technical basis and the changes from the first year's effort and the knowledge acquisition efforts. The section entitled Results discusses the results and presents lessons gleaned from this project.

Part

2

Technical Description

Methods, Assumptions, and Procedures

Technical Basis

Tracking can be viewed as consisting of two steps. The first is a projection of possible future locations of the object in track, the second is the correlation of the object with those objects which seem to be near the expected location at a time. This identifies the tracked object. The field of tracking is well studied and under certain conditions, there are adequate techniques to perform tracking. As a rule of thumb, when the control forces on the object are large enough to enable significant lateral velocity change within the observation time, traditional methods may encounter difficulties. The knowledge approach described in this report is expected to be used in situations where other methods fail to perform adequately. There are also situations where the knowledge techniques described in this report are not appropriate. The initial task was to identify track situations where these knowledge based methods offer additional capability, either when combined with traditional methods of tracking, or when providing a best guess where no other traditional method can perform. This allows a graceful degradation in the overall tracking system. The underlying concept behind the knowledge based approach is to focus on the driver-vehicle system, and how it can interact with the surroundings. The fundamental assumption in this study is that observed ground vehiclesare guided by some intelligence, i.e. the driver. That intelligence applies controlling forces to the vehicle that causes the vehicle to select a path. The vehicleis then observed by some sensing system that has a fundamental resolution and a periodic observation rate at which the vehicle is sensed. There are three general cases to consider. First, when there is no control applied to the vehicle, it is then guided by basic physics of the world around it. With detailed vehicle characteristics and terrain information, the ground pathcan be predicted reasonably well and the vehicle tracked closely. Second is the case where the vehicle is controlled, but the control forces are small, so that the impulse imparted are small in the time interval between observations. The driver's control is then a perturbation on the previous case and tracking filters can handle this case readily. Third, there is the case in which the control impulse on the vehicle may be large within the time of observation. Consequently, the vehicle may radically alter its pathon the earth's surface between observations. This third case is the one of interest in this study. Since this situation bears a strong resemblance to an under sampled time varying signal, a closer look at the third case is required.

At any given instant, the driver may choose to change directions or speed of the vehicle. First, assume a constant speed. The driver selects a new direction and applies a turning force to the vehicle. Neglecting weight shifts and toppling forces, the turn is limited by the frictional sticking of the tires or treads on the road surface. The maximum lateral force, F, which the vehicle can withstand, without slipping, is:

$$F \leq \mu * W$$

Where μ is the coefficient of friction and W is the weight of the vehicle, and $W = m * g$ where m is the vehicle mass and g is the gravitational constant. Even with modest coefficient values for trucks [Marks, 1967] of 0.53, the maximum lateral force is:

$$F = 0.53 * m * g$$

Given that this lateral force is "centrifugal force", then the acceleration is

$$(\mu * W)/m = V^2 / r$$

Where, V = velocity of the vehicle, and r = radius of the selected turn

Or,

$$\mu * g = V^2 / r$$

Then,

$$r = V^2 / \mu * g$$

If the driver executes a right hand turn, the distance is Q, the length of the quadrant of the turning circle, and

$$Q = (\pi * r) / 2 = V * t$$

Where, t is the time to execute the turn. Solving for t

$$t = (\pi * r) / (2 * V) = (\pi * V) / (2 * \mu * g) \approx 0.0926 * V, \text{ if V is feet per second}$$

At 30 miles per hour, a truck is going about 44 feet per second, so the right turn takes about 4 seconds, and a U-turn (two right turns) about 8 seconds. Unless there is a way to predict the driver's behavior, the choice of turns is potentially random choices.

Consider the driver's options. Assume the driver either maintains or decreases the present speed. The driver can proceed ahead, turn left or right, and perform a U-turn. Every 4 seconds, the constant speed 30-mph truck can be anywhere inside a box that is about 176 by 228 feet in size. Assume a resolution of about the size of the truck. If a truck is about6 by 20 feet, then in that 4 seconds, there are about 341 distinct cells it can be within that box. Since all cells are equally likely, unless we sample at less than 4 seconds, there is a uniform probability of 1/341 or about 0.0029 of randomly selecting the correct cell. If three or more observations are needed to establish a track, then there is about $2.4\text{x}10^{-8}$ chance of correctly selecting the cell sequence. Other casesare visited in Appendix A. Despite appearances, this is not a hopeless task, even if the revisit time remains larger than the turning time.

The solution to this problem is to reduce the number of cells that the truck could be in at the time the track decision is made. This can be accomplished by identifying the cells where the driver wants to go, rather than just the cells where the driver can go. If no other trucks are present within the narrow range of cells, then the truck is easy to track. When other trucks are within the narrow range of possible cells, then the additional problem of correlating one of these with the tracked object truck remains. In this classification problem, the feature space may not allow unambiguous correlation. The top guessesare then carried until the obviously incorrect paths can be pruned. Another solution is to unambiguously identify that specific truck in only one cell after exhaustively searching all the cells by utilizing an improved feature space. An example of the second solution is to utilize a short wavelength, high resolution radar system.

First Year Overview

The first year of this effort focused on the preparation of the infrastructure needed to support the knowledge based tracking, as discussed in the introduction and detailed in (Skipper, 1999). Consequently, the work of the first year was a software development process. This proceeded as:

1) Requirements,

2) Design,

3) Interface Definition,

4) Implementation,

5) Knowledge Modeling.

The knowledge modeling was tobe based on data sets and ground truth data delivered by the government in support of this project.

Based on the three objectives identified previously, BRC developed a set of working requirements for tools for this development. Using the Motorola developed Time Critical Target Aid system (TCTA) as the government platform of choice, the requirements are:

1) The BRC tool set system shall connect with the TCTA system. It shall exchange information with this system.

2) The BRC tool set system shall provide tools to enhance target tracking and identification using data provided by TCTA and the TCTA operator.

3) The BRC tool set system shall automate selected operator actions to reduce the operator workload.

In the second year, the TCTA was no longer a viable option and BRC developed its own display and data manipulation system to provide these basic capabilities instead of the TCTA.

Second Year Overview

Goals

BRC first goal for the second year of the project was the development of the knowledge needed to perform tracking. This was to be accomplished by study of data sets provided by the government or through the TCTA contractor. The approach was to either correlate the data and the ground truth to arrive at an understanding of the vehicle driver, or by studying a very large set of data to determine underlying patterns within the data.

The second goal was to enhance the basic system to remove known defects and to add improvements as time permitted.

Results

During the second year, the second goalwas accomplished. However, the first goal was troublesome. BRC repeatedly requested data sets, from the government and was promised data sets. BRC repeatedly requested cooperation from the TCTA contractor to facilitate incorporation of the tracker software into TCTA so that data sets could be examined directly. All of these are well documented in the monthly reports. When the basic contract time began to expire, and not data was forthcoming, BRC requested a no cost extension to the contract, and received that. BRC substantially reduced the efforts on the contract to give the government time to acquire the needed data and get that data to BRC, with the expectation that the project could then be restarted and the major goal accomplished. The data was never delivered. On its own initiative BRC contacted CECOM who was also unable to get data from the TCTA contractor and AFRL. AFRL was contacted at the end of the contract and they had simulated data, without ground truth and at a higher rep rate than expected. One CDROM of this simulated data was delivered to BRC and it was studied (Appendix B), but its arrival so late in the program without the ground truth made final use virtually impossible. This one CDROM represented the only knowledge data of any kind delivered by any government group in support of this project. Any future investigations in this field should begin with contacting AFRL for data at the beginning of the study.

Knowledge Modeling

Acquisition

Given the substantial difficulty acquiring data sets for knowledge acquisition, the only knowledge capabilitieswere based on an implicit knowledge of driving vehicles. This led to simple bulk filters to exclude tracks that were clearly not in the area of interest, and on simplistic vehicle knowledge. This implicit knowledge was only used for debugging the system.

Modeling

The basis for knowledge modeling in this system is the conceptual graph (Sowa, 1984). Appendix C shows the knowledge models which were developed as prototypes in the absence of any knowledge to model.

Implementation

A conceptual graph processor developed for another program and itwas re-hosted onto the SUN computer to permit installation of the knowledge graphs described previously.

Part

3

Program Results

Results, Discussion, and Conclusions

Results and Discussions

BRC began this project with the hypothesis that object tracking would be possible in difficult cases by focusing on the driver and the limitations of the vehicle in a given environment. BRC proposed testing that hypothesis by acquiring knowledge of the terrain, drivers and military operations from data provided by the government. Unfortunately, due to reasons noted previously, this hypothesis is neither proven nor disproven. This hypothesis awaits future studies for a conclusive result. As a secondary goal, the usefulness of conceptual graph representations of knowledge would also be demonstrated. Again thiscould not be proven or disproven.

BRC clearly learned several lessons in this project. First is not to underestimate the reluctance of a major contractor (TCTA) to assist a small contractor. Similarly, never underestimate the time and effort to obtain data sets, even if they areabsolutely critical to a program. Finally, initial planning should assume that datawill never be made available, and time should be spent preparing simulations and synthetic terrain as a backup to the missing data sets.

Conclusions

BRC realized several conclusions from this effort.

1) Certain tracking situations may be resolved by using knowledge-based approaches. However, the actual demonstration of that hypothesis awaits a future project.

2) The MTI data sets from AFRL may provide the basis for simulated data needed to prove or disprove the previous hypothesis. However, the data sets must be packaged as complete knowledge sets, with ground truth, terrain, mission statements, force descriptions, and weather information to be of truly useful for knowledge acquisition.

3) The standardized MTI data set interface definition from AFRL appears to be quite useful and should provide a basis for future tracking studies.

In summary, the second year of this project was one of extreme frustration for the participants. Although numerous avenueswere pursued to find data sets, all these efforts were stymied until the end of the project. What could have been a useful product for inclusion into a government system was a knowledge processor bereft of the knowledge needed to actually function as a tracker.

References

Baumeister, T., Editor in Chief, *Mark's Standard Handbook for Mechanical Engineers, Seventh Edition*, 1967, New York, NY, McGraw Hill.

Skipper, D.J., *A Dialectic Approach to Moving Target Indicator (MTI) Correlation, Interim Technical Report*, 1999, BRC-TR-0042-99/001.

Sowa, J.F., *Information Processing in Mind and Machine*. 1984, Reading, MA: Addison-Wesley Publishing.

Appendix

A

Vehicle Turn Limits

Finding a Vehicle

Time to Turn

The following table shows the time to execute a constant speed turn assuming the 0.53 coefficient of friction. The times are in seconds. The percentages represent a fractional part of a 90 degree turn.

Turn at speed (mph)	PI/2	90%	80%	70%	60%	50%	40%	30%	20%	10%
10	12.68	10.70	8.76	6.93	5.23	3.71	2.42	1.38	0.62	0.16
20	50.73	42.80	35.06	27.70	20.91	14.86	9.69	5.53	2.48	0.62
30	114.15	96.29	78.88	62.33	47.05	33.43	21.80	12.44	5.59	1.41
40	202.94	171.19	140.22	110.80	83.65	59.44	38.76	22.12	9.93	2.50
50	317.09	267.48	219.10	173.13	130.71	92.87	60.56	34.56	15.52	3.90
60	456.60	385.18	315.51	249.31	188.22	133.74	87.20	49.77	22.35	5.62
70	621.49	524.27	429.44	339.34	256.19	182.03	118.69	67.74	30.42	7.65
80	811.74	684.76	560.90	443.22	334.61	237.75	155.03	88.47	39.73	9.99
90	1027.36	866.64	709.89	560.95	423.49	300.91	196.21	111.98	50.28	12.65
100	1268.34	1069.93	876.40	692.53	522.83	371.49	242.23	138.24	62.08	15.62

• Table A 1 Turn Times

Offset From Straight Line

At the end of the turn, the vehicle is the specified distance from the centerline of travel.

Turn at speed (mph)	PI/2	90%	80%	70%	60%	50%	40%	30%	20%	10%
10	12.68	10.70	8.76	6.93	5.23	3.71	2.42	1.38	0.62	0.16
20	50.73	42.80	35.06	27.70	20.91	14.86	9.69	5.53	2.48	0.62
30	114.15	96.29	78.88	62.33	47.05	33.43	21.80	12.44	5.59	1.41
40	202.94	171.19	140.22	110.80	83.65	59.44	38.76	22.12	9.93	2.50
50	317.09	267.48	219.10	173.13	130.71	92.87	60.56	34.56	15.52	3.90
60	456.60	385.18	315.51	249.31	188.22	133.74	87.20	49.77	22.35	5.62
70	621.49	524.27	429.44	339.34	256.19	182.03	118.69	67.74	30.42	7.65
80	811.74	684.76	560.90	443.22	334.61	237.75	155.03	88.47	39.73	9.99
90	1027.36	866.64	709.89	560.95	423.49	300.91	196.21	111.98	50.28	12.65
100	1268.34	1069.93	876.40	692.53	522.83	371.49	242.23	138.24	62.08	15.62

• Table A 2 Vehicle Offsets

Indeterminate Area

Once the turn time is completed, there is a large area that could contain the vehicle.

Turn at speed (mph)	PI/2	90%	80%	70%	60%	50%	40%	30%	20%	10%
10	505	384	279	193	125	74	39	17	5	1
20	8086	6139	4470	3091	2000	1184	618	264	79	10
30	40936	31079	22629	15646	10125	5995	3127	1339	401	50
40	129379	98226	71519	49450	31999	18947	9884	4230	1266	159
50	315867	239809	174607	120726	78123	46258	24130	10328	3092	389
60	654981	497268	362065	250338	161996	95920	50036	21417	6411	806
70	1213434	921250	670770	463782	300117	177703	92698	39677	11878	1494
80	2070064	1571611	1144303	791192	511987	303154	158139	67687	20263	2549
90	3315843	2517417	1832953	1267337	820104	485594	253308	108422	32458	4082
100	5053868	3836942	2793709	1931622	1249967	740122	386081	165252	49471	6222

• Table A 3 Indeterminate Area

Number of Cells

Assuming a truck roughly 20 by 6 feet, the truck can be in any one of the possible cell locations within the indeterminate area.

Turn at speed (mph)	PI/2	90%	80%	70%	60%	50%	40%	30%	20%	10%
10	4	3	2	2	1	1	0	0	0	0
20	67	51	37	26	17	10	5	2	1	0
30	341	259	189	130	84	50	26	11	3	0
40	1078	819	596	412	267	158	82	35	11	1
50	2632	1998	1455	1006	651	385	201	86	26	3
60	5458	4144	3017	2086	1350	799	417	178	53	7
70	10112	7677	5590	3865	2501	1481	772	331	99	12
80	17251	13097	9536	6593	4267	2526	1318	564	169	21
90	27632	20978	15275	10561	6834	4047	2111	904	270	34
100	42116	31975	23281	16097	10416	6168	3217	1377	412	52

• Table A 4 Number of Cells

Probability of Finding

One Selection

After completing a turn, the chance of randomly finding the truck in the indeterminate area is listed below.

Turn at speed (mph)	PI/2	90%	80%	70%	60%	50%	40%	30%	20%	10%
10	23.7442%	31.2749%	42.9536%	62.1240%	96.0025%	100.0000%	100.0000%	100.0000%	100.0000%	100.0000%
20	1.4840%	1.9547%	2.6846%	3.8827%	6.0002%	10.1335%	19.4260%	45.3853%	100.0000%	100.0000%
30	0.2931%	0.3861%	0.5303%	0.7670%	1.1852%	2.0017%	3.8372%	8.9650%	29.9466%	100.0000%
40	0.0928%	0.1222%	0.1678%	0.2427%	0.3750%	0.6333%	1.2141%	2.8366%	9.4753%	75.3357%
50	0.0380%	0.0500%	0.0687%	0.0994%	0.1536%	0.2594%	0.4973%	1.1619%	3.8811%	30.8575%
60	0.0183%	0.0241%	0.0331%	0.0479%	0.0741%	0.1251%	0.2398%	0.5603%	1.8717%	14.8811%
70	0.0099%	0.0130%	0.0179%	0.0259%	0.0400%	0.0675%	0.1295%	0.3024%	1.0103%	8.0325%
80	0.0058%	0.0076%	0.0105%	0.0152%	0.0234%	0.0396%	0.0759%	0.1773%	0.5922%	4.7085%
90	0.0036%	0.0048%	0.0065%	0.0095%	0.0146%	0.0247%	0.0474%	0.1107%	0.3697%	2.9395%
100	0.0024%	0.0031%	0.0043%	0.0062%	0.0096%	0.0162%	0.0311%	0.0726%	0.2426%	1.9286%

• Table A 5 Probability of Finding Truck with One Chance

Sequential Selections

The consequences of a three hit track initiation requirement given the previous probability

Turn at speed (mph)	PI/2	90%	80%	70%	60%	50%	40%	30%	20%	10%
10	1.3387%	3.0591%	7.9250%	23.9760%	88.4806%	100.0000%	100.0000%	100.0000%	100.0000%	100.0000%
20	0.0003%	0.0007%	0.0019%	0.0059%	0.0216%	0.1041%	0.7331%	9.3486%	100.0000%	100.0000%
30	0.0000%	0.0000%	0.0000%	0.0000%	0.0002%	0.0008%	0.0057%	0.0721%	2.6856%	100.0000%
40	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0002%	0.0023%	0.0851%	42.7565%
50	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0002%	0.0058%	2.9382%
60	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0007%	0.3295%
70	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0001%	0.0518%
80	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0104%
90	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0025%
100	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0007%

- Table A 6 Probability of Finding Truck Three Times in a Row

Closing Comments

From the brief analysis above, a truck with modest tire capability on a flat open surface has sufficient options to make tracking the truck with a revisit time longer than a small fraction of the time to turn is not feasible unless the drivers options are reduced. For a road surface without turn options, a driver is limited. For off road conditions with terrain limitations such as hills, vegetation, soft surfaces, or local ruggedness, the driver's options can also be reduced. If no means of reducing the driver's options are available, and then the remaining option is to significantly reduce the revisit time, which effectively removes the driver's options.

Appendix

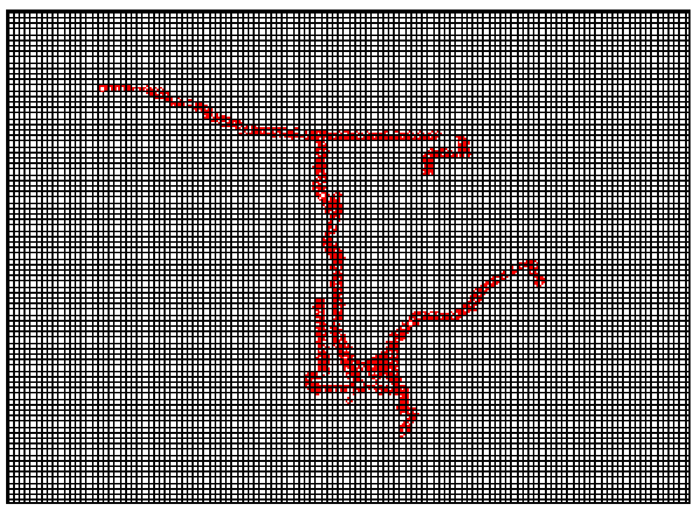
B

AFRL Data Set

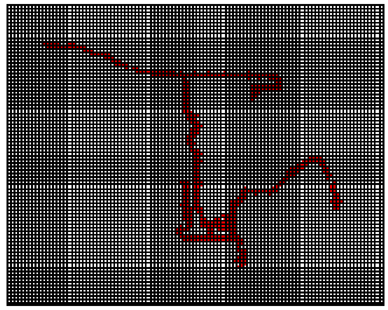
Contents and Utility

Data Description

The simulated data sets were in two categories. One category was labeled v1.01. It contained 12 sets of MTI data in the NMTI format. The v1.01 data sets were in two distinct groups. The first group consisted of six sets in about longitude –106 46 0 latitude 32 26 53 to about longitude –105 38 8 33 39 24 latitude. The second group of six was near longitude –106 34 27 32 24 19 latitude to about longitude –105 29 28 latitude 33 34 42. Each set in each group strongly resembled other sets in the group. The vehicles appeared to be constrained to follow a road network. Since there was no ground truth provided, knowledge acquisition for predictive tracking was non-existent, but the clear patterns shown in figures B 1 and B 2 show the traffic analysis content of a sample of each group in v1.01.

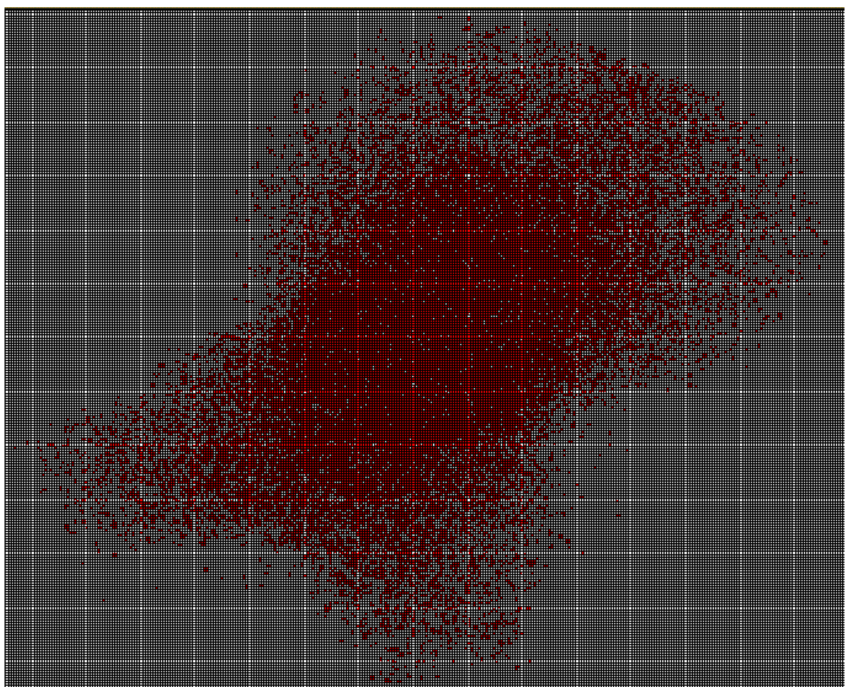


• Figure B 1 Set 1 Group 1 V1.01



• Figure B 2 Set 1 Group 2 V1.01

The second simulated data collection was labeled v1.1. This consisted of two sets in a rough area longitude 20 6 52 latitude 41 58 0 to about longitude 21 36 48 latitude 43 11 2. The data consisted of two separate sets. From the example shown in figure B 3, it is clear that the objects are either constrained to a much finer road network or there are no constraints. Again, ground truth was not provided, which limited the utility of the data sets.



• Figure B 3 Set 1 V1.1

Conclusions

The appearance of the sets in indicates the usefulness of road constraints, which requires accurate road network data. The terrain shape is not explicitly seen in these sets but the road network seems to be influenced by the terrain shape, so that the traffic is further constrained by the terrain. The second data sets, in v1.1 show initial growths indicative of road patterns that seem to support the road utility hypothesis. Again, the terrain use is not immediately available. Nothing in the data indicates mission or driver requirements or weather. Future efforts should investigate these clues.

Appendix

C

Knowledge

The following figure, C1, contains the general knowledge categories that are to be used in the development of the system. Figures C2 and C3 give a top-level breakdown of the

- **Spatial Groupings**
  - **Order of Battle**
  - **TTP’s**
  - **Commander’s Intent**
  - **Sensor Data**
  - **TCTA Formats**
- **Temporal Groupings**
  - **Temporal extent**
- **Terrain**
  - **Natural objects**
  - **Manmade objects**
  - **Vegetation**
  - **Inter-visibility**
  - **Terrain Common Sense**
- **Weather**
  - **Mobility**
- **Targets**
  - **Size, weight, RCS, etc.**
- **System Behavior**

Figure C1 Knowledge Categories

knowledge that is used to guide the acquisition. Figures C4, C5, C6, and C7 are additional knowledge models being developed for the second phase. They represent heuristic portions of the knowledge. The full spellings of the shorthand terms in the graphs are presented below Figure C7.

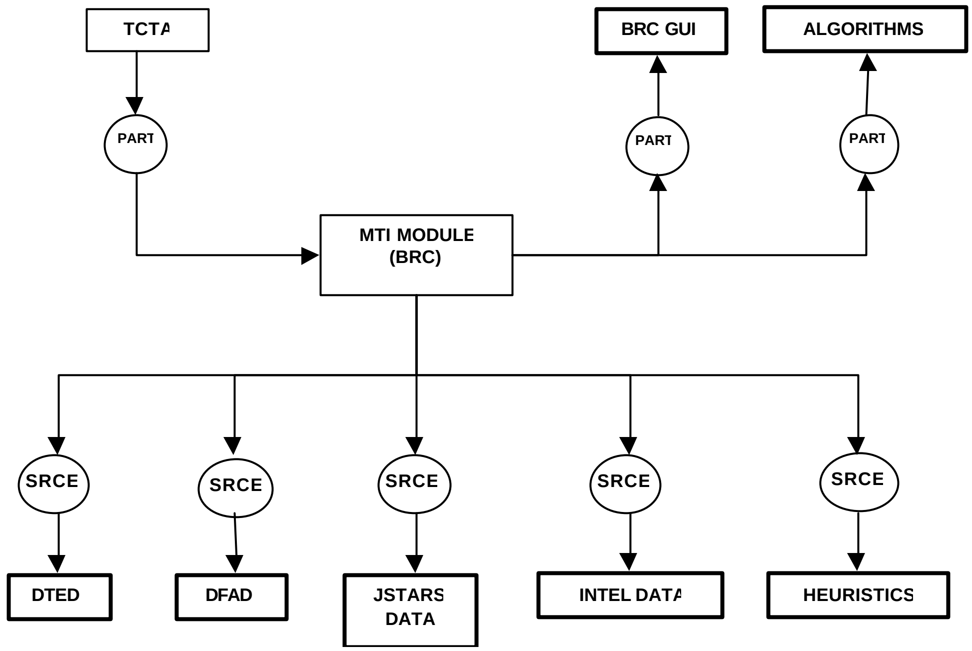


Figure C2 Top Level Knowledge Structure

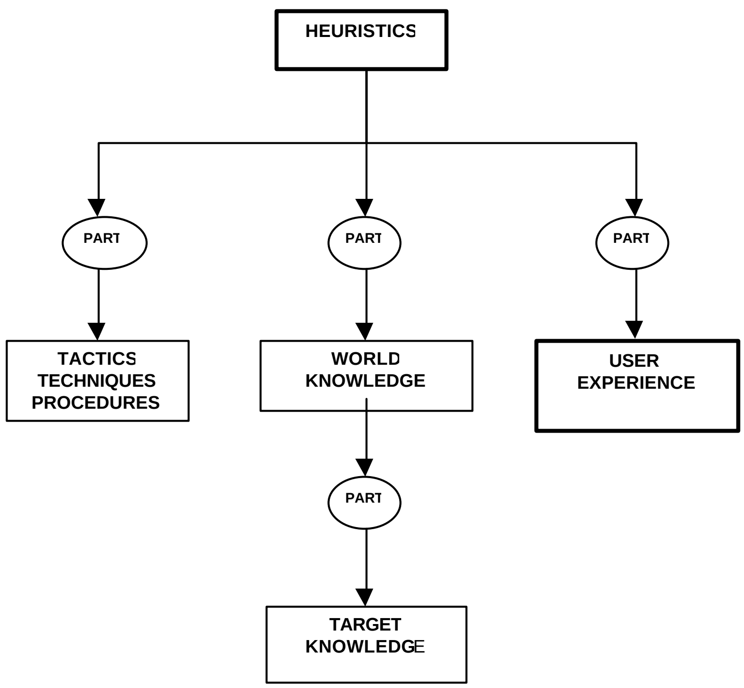


Figure C3 Heuristic Structure

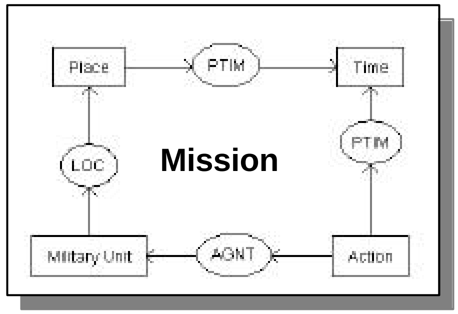


Figure C4 Mission Concept

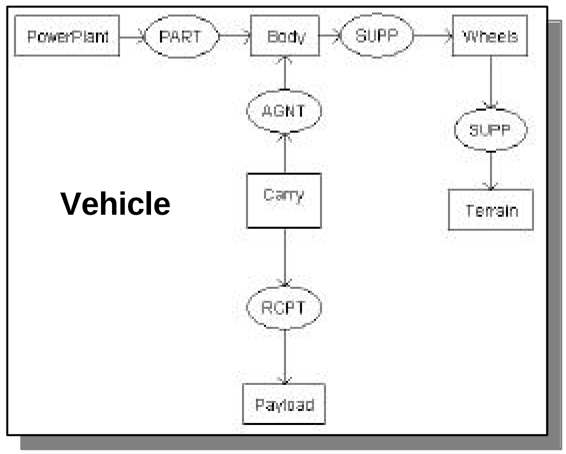


Figure C5 Vehicle Concept

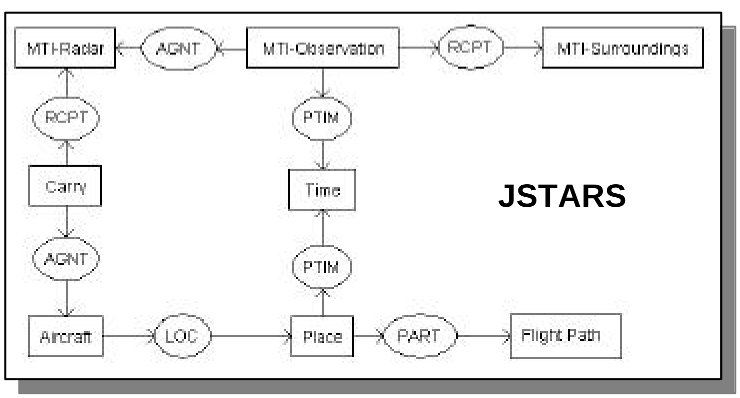


Figure C6 JSTARS Concept

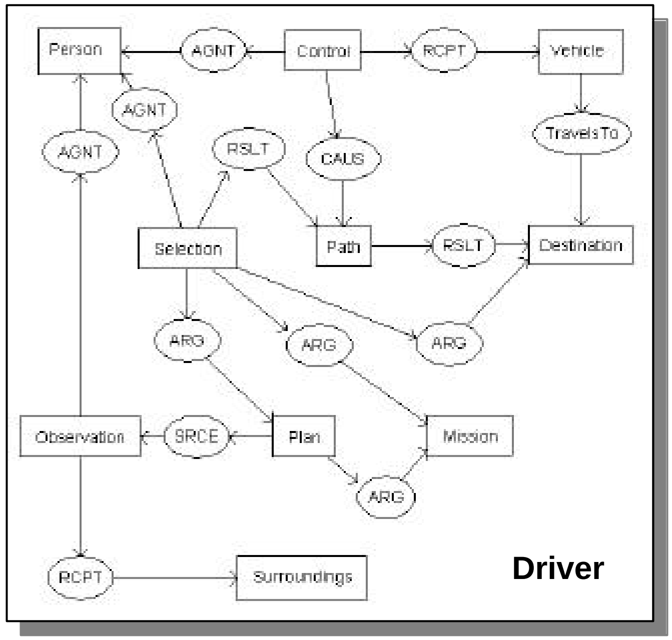


Figure C7 Driver Concept

SRCE	Source
PTIM	Point in Time
AGNT	Agent
SUPP	Support
RCPT	Recipient
ARG	Argument
RSLT	Result

Acronyms

BRC	Bevilacqua Research Corporation
GUI	Graphical User Interface
JSTARS	Joint Surveillance Tracking and Reconnaissance System
MTI	Moving Target Indicator
RCS	Radar Cross Section
SBIR	Small Business Innovative Research
TCTA	Time Critical Targeting Aid